ASSESSING STREAM VULNERABILITY TO MINE DRAINAGE AND ACID DEPOSITION IN THE MID-ATLANTIC BY MAPPING PROBABILITY SAMPLE DATA FROM EMAP AND THE NATIONAL STREAM SURVEY

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ASSESSING STREAM VULNERABILITY MINE DRAINAGE

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ABSTRACT

A new approach was evaluated for use in assessing impacts from stressors on aquatic systems. Two probability surveys of stream chemistry in the Mid-Atlantic Region, the National Stream Survey Study (NSS) and the Environmental Monitoring and Assessment Program/Mid-Atlantic Highland Assessment (EMAP/MAHA), study were used to map estimates of the percentage of stream miles impacted by mine waste. Within the study area, the NSS sampled 433 stream segments in spring 1986. In the EMAP study, 508 sites were sampled during late spring 1993-1995. Macroinvertebrate samples were also collected at these same EMAP sites. A chemical classification scheme was used to identify sites as impacted by mine drainage (both acidic and nonacidic), acid deposition, mixed or clean. Using the EMAP probability design, we then estimated the percentage of stream length in various ecoregions impacted by mine wastes and acid deposition. The results of these analyses were used to construct colored maps of the Mid-Atlantic Region using aggregations of Level IV Omernik ecoregions. Over 50% of the stream length in the mixed land use, Greenbrier Karst, and Cumberland Mountains Subecoregions of the Central Appalachians were affected by mine drainage. In the Western Allegheny Plateau, 26% of the stream length were mining impacted. The macroinvertebrate data were put into a candidate index called the Stream Benthos Integrity Index (SBII). Excellent, good, fair, poor and very poor SBII scores were also plotted on the aggregated Ecoregion map. Areas of severe, moderate, slight and undetectable (> 50%, 25-50%, 10-25%, and 1-10% of stream length, respectively) mine waste exposure were compared to the SBII scores. Results indicate that this approach is useful in illustrating stressor extent, biological condition and a method for evaluating chemical and biological assessment models.

INTRODUCTION

The U.S. Environmental Protection Agency's (U.S. EPA) Office of Research and Development (ORD) has adopted a comprehensive strategy based upon the risk assessment paradigm as the integrating principal for research program development and project prioritization. The paradigm provides a scientific framework for risk reduction and targets available resources at those stressors that account for the greatest impact to both human and/or ecosystem receptors. Ecological vulnerability evolves from the susceptibility and sensitivity to change as a result of the changing stressor regimes. ORD has focused its ecological research program to join with other state and federal agencies in filling those critical gaps in our understanding that will strengthen the preservation of our natural resources. To facilitate the assessment and relative ranking of stressor importance within large geographic regions, the National Exposure Research Laboratory (NERL/EPA), is developing advanced methods and tools to enhance the Agency's ability to assess stressor exposures to ecosystem receptors. By 2008, EPA researchers will have developed the next generation of measurements and models necessary to assess the present and probable future vulnerability of ecosystems at local, watershed and regional scales.

U.S. EPA has the unique mandate for addressing broad-scale environmental issues that overlap political and physiographic boundaries. As such, EPA has the primary responsibility for evaluating the risk of natural and human induced stressors on ecological receptors across the nation's ecosystems. This will be accomplished initially by utilizing existing sources of data and by projecting (through the use of models) the changes in ecological stressors and receptors in both distribution and extent over time. By definition, an exposure is defined as the co-occurrence of stressor and ecosystem receptor in space and time.

Regional vulnerability assessment (ReVA) can be defined as the assessment of the likelihood that stressors to ecosystems will cause ecological processes and functions to vary beyond the range of natural variability, i.e., subsequent adverse effects could reduce that ecosystem's ability to provide the ecological goods and services that the public has come to expect and desire. Specifically, the goal of the ReVA program is to determine and forecast the extent, distribution, and vulnerability of the ecological resources based on the forecast of changes in chemical, physical, and biological stressors.

U.S. EPA's Regional Vulnerability Assessment Program (ReVA) can contribute to this strategic plan by preparing a stressor atlas that is based upon chemical and biological information obtained from the National Stream Survey (NSS) , National and Regional Environmental Monitoring and Assessment Program (EMAP, REMAP) and the Region 3 Fisheries Survey monitoring efforts.

Based upon observed and predicted changes in chemical and non-chemical, natural and human-induced stressors, the tools developed by the ReVA program will serve as the scientific foundation required to ensure that the Agency can: (1) identify those ecosystems most sensitive to, and the characteristics of, specific stressor exposures; (2) understand the mechanisms of adverse effects to ecosystems resulting from increases in either single and multiple stressors; (3) define the relative risk posed by multiple stressors on specific ecosystem receptors; (4) characterize mediated effects of adverse stressors in terms of ecosystem sustainability and vulnerability; (5) provide cost effective options to manage and reduce the risk of ecosystem degradation; (6) maintain or restore current ecosystem integrity, and ensure future sustainability; and finally, (7) provide the scientific understanding necessary for decision makers to avoid costly environmental management failures.

ADD OBJECTIVES/GOALS for this paper, ReVA Study area, etc. (1-2 paragraphs)

METHODS

Data for this regional analysis was taken from three sources;

- EPA's National Stream Survey (NSS)
- EPA's Environmental Monitoring and Assessment Program (EMAP) Stream Pilot
- EPA Region 3 Regional Biologist Survey

The NSS was a probability sample of blue-line segments from 1:250,000 scale USGS maps conducted in 1986 primarily to assess the effects of acidic deposition on streams. Most of the ReVA study area is within the study area of the NSS except for parts of the Coastal Plain in North Carolina, parts of upstate New York, and the western portions of West Virginia and Pennsylvania (Fig. 1). These areas were not expected to have acid neutralizing capacities below 400 μeq/L so were not included in the NSS study area. Blue line segments with total watershed area greater than 155 km^2 were not sampled. In the mid-Atlantic, water chemistry samples were taken from both the upstream and downstream end of each stream segment at two times in a spring (April 15-June 15) baseflow index period (Kaufmann et al., 1988, 1991; Herlihy et al., 1991). In the mid-Atlantic ReVA study region, there were 443 NSS stream segment ends sampled.

As part of EMAP stream pilot activities, a probability sample of first, second and third order (wadeable) blue-line streams in EPA's River Reach File Version 3 (RF3) was conducted in 1993-1995. The hydrography in RF3 is based on the 1:100,000 scale USGS maps. The study area included all of the EPA Region 3 states plus the Catskill Mountains of southeastern New York (Fig. 1). Streams were sampled in spring (April 15-July 1) for a suite of biological, chemical, and physical habitat indicators (Klemm and Lazorchak, 1994). Over the 3 year EMAP study, 509 probability selected stream sites were sampled for stream chemistry and macrobenthos.

The Regional Biologists Fishery Survey was compiled as a digital database of streams in RF3 impacted by mine drainage based on interviews with state fisheries biologists and other specialists. The biologists surveyed are believed to be the best source of current professional scientific information for the quality of streams in their area. Data was downloaded from the world wide web (http://www.epa.gov/reg3giss/datalib/metamd95.htm).

Both the NSS and EMAP measured all streamwater major anions/cations, and acid-base analytes. Water samples were shipped by overnight courier to the analytical laboratory where they were processed and stabilized with 48 hours of collection. For variables of particular interest to the ReVA mine drainage assessment, sulfate, nitrate and chloride were measured by ion chromatography, acid neutralizing capacity (ANC) by gran titration with hydrochloric acid, and iron and manganese by atomic absorption (Hillman et al., 1987). Closed headspace syringe samples were used to measure pH in the analytical laboratory within 48 hours of collection. All sampling in EMAP and the NSS was conducted according to EPA approved QA plans and included analyzing QA audit samples to quantify accuracy, precision and detection (e.g., Cougan et al., 1988).

Water Chemistry Data Analysis

All EMAP and NSS sites were classified based on water chemistry using methodology developed by Herlihy et al. (1990, 1991). Sites were divided into an acidic and non-acidic group using an ANC criteria of 25 µeq/L. Streams with ANC below 25 µeq/L are either chronically acidic (no acid neutralizing capacity; ANC < 0) or transiently acidic (ANC 0-25). Acidic streams were further classified into acidic deposition impacted or mine drainage impacted using a sulfate criteria of 400 µeq/L. The dominant acid anion in both acidic deposition and acid mine drainage is sulfate. In the mid-Atlantic, streamwater sulfate concentrations based on evapoconcentration of sulfate in deposition are expected to be around 200-250 µeq/L. Streams with sulfate below 400 µeq/L have sulfate anion composition dominated by deposition sources. Similar, streams with sulfate above 400 µeq/L have sulfate anion composition dominated by internal watershed sources (mining). Non-acidic streams with sulfate concentrations above 1000 µeq/L in the Appalachian Plateau were classified as non-acidic, mine drainage impacted. In both the NSS and EMAP, sites in the Appalachian Plateau with sulfate greater than 1000 µeq/L had evidence of mining activity in their watersheds on 7.5" USGS maps and/or in the crew field notes. In general acidic streams are more severely impacted by mine drainage than non-acidic streams because the water itself is toxic to many organisms due to low pH and high metal concentrations. While the water in the nonacidic, mine drainage impacted streams is not toxic, these sites are often impaired by sedimentation, armoring, sediment metals, and physical habitat alteration due to mine drainage. The high sulfate concentrations in these sites serves as an excellent indicator of mine drainage impacts in the watershed.

Macrobenthos Data Analysis

Macrobenthos samples were collected from all EMAP sites. Data from the 1993 and 1994 surveys will be presented here. In the field, kick samples were collected from 9 equidistant stream transects at each site. Samples were combined in the field into one fast water habitat and one slow water habitat composite at each site. In the laboratory, 300 individuals were identified and enumerated from each composite. For the purposes of this analysis, the fast and slow water sample data were combined to calculate single metric scores for each stream sample site.

Macrobenthos candidate metrics were compiled from various states, other agencies, and the published literature (PA, VPI, SBII, DE, WV, VA, MD, Mon. (Monroe County, PA), NJ, NY, OH, B-IBI (Kerans and Karr, 1994), RBP (III) (Plafkin et al., 1989), RBP (Barbour et al., 1992), B-IBI (Fore et al., 1996), and FL (Barbour et al., 1996)). These metrics were complied and compared to the NERL - Cincinnati multimetrics (Table 1) used for the Stream Benthos Integrity Index (SBII). The lists indicated that a core of five metrics were used regularly by all or most of these organizations. The metrics were Taxa Richness, HBI, EPT Richness, % Individual in Dominant Taxon, and % EPT. Other individual metrics used at various times by the states are listed. These were generally used for specific bioassessment purposes.

The SBII is a multimetric method for pools or riffles and the composite of pools and riffles that integrates 10 macroinvertebrate community or population parameters (metrics) into a single biological integrity index score and biological condition following the general scheme used by Plafkin et al. (1989). Three approaches were taken in the development of the SBII method: (1) use of scientific literature and data to determine the individual metrics to use as biological indices for MAHA, (2) best professional judgement, and (3) some SAS and PCA analyses, comparing

individual metrics and SBII using various chemical and physical habitat variables. The multimetrics that are proposed are an initial attempt to develop a workable SBII. However, as more research is completed and information becomes available, the SBII will be revised as needed.

Scoring criteria and ranges used to determine the score for each metric (Table 1) were assigned by professional judgement using information form the literature, personal experience, and experimentation on the EMAP mid-Appalachian mountain sites. These ranges were assigned to scores of zero (0) to five (5) corresponding to the five categories of biological condition (e.g., reference (0), excellent (1), good (2), fair (3), poor (4), and very poor (5). Each parameter, or metric, measures a different component of the community structure and has a different range of sensitivity to pollution and environmental stress. Scores for the 10 metrics are then totaled to get the SBII value for the pool or riffle sites. We found that the use of the 10 multimetrics worked effectively after the metric ranges were adjusted in calculating the SBII score and biological condition. Note that scores can range from 0 to 50 with high scores denoting poor condition and low scores denoting good condition.

Regional Mapping

In order to geographically display the extent of mine drainage impacts in the mid-Atlantic, we used Omernik's level 4 ecoregions as a regional framework (Woods et al., 1996).

Many other geographic subdivisions could be used for such a display (states, river basins, MLRAs, etc.) but we felt that these ecoregions do a good job of putting boundaries in the framework of mine drainage and acidic deposition vulnerability. Sample sizes of 30 are deemed necessary to make robust subpopulation estimates of conditions. The EMAP database lacked this sample size/resolution to estimate each one of Omernik's level 4 subecoregions so we were forced to aggregate them to level 3 ecoregions or combinations of level 4 subecoregions in many areas (Table 2).

Within each of these areas, the EMAP probability sample data was used to estimate the percent of the total stream length in the region impacted by mine drainage (both acidic and non-acidic). The results were then graphically displayed by coloring each ecoregion aggregate according to the percentage of impacted stream length. Regions where greater than 50% of the stream length was impacted were colored as red, 25 - 50% impacted length were colored orange, 10 - 25% as yellow, 1 - 10% as green, and < 1% as blue. For macrobenthos, a similar map was constructed for the same ecoregion aggregates using a stream biotic integrity index > 20 (the cutoff between good and fair condition) as a cutoff value indicative of benthos impairment.

RESULTS

Streams in the Region 3 fish biologist survey were divided into two classes; severe fish loss and some fish loss (Fig. 2). In the severe fish loss class most if not all of the fish have been eliminated from the stream. A few fish may be found near springs or where a tributary dilutes the stream. In the some fish loss class, impacts include reduced number of species of fish and/or reduced productivity. There was a high degree of overlap between stream traces impacted by mine drainage as documented by the regional biologist survey and the location of mine drainage impacted EMAP/NSS stream sites classified by water chemistry (Fig. 2). Mine drainage impacts are almost exclusively found in the coal bearing region of the study area. Using the EMAP probability sample data to estimate regional condition, 31% of the 47,000 km of stream in the coal bearing region were mine drainage impacted (Fig. 2). On the other hand, only 2% of the 138,000 km of streams outside the coal bearing region were mine drainage impacted. Acidic, mine drainage systems were more common in the northern half of the study area (Fig. 2). The presence of calcareous rock formations in the southern part of the region (southern West Virginia/Virginia) neutralize the AMD-acidity but do not change the sulfate concentrations (Herlihy et al., 1990).

The aggregate ecoregions most strongly impacted by mine drainage were in the Central Appalachians where in the Greenbriar/Cumberland area 66% of the stream length showed chemical evidence of mine drainage and in the Mixed Land Use subecoregion where 54% of the stream length was impacted (Fig. 3). Mine drainage impacts were also common (26% of the length) in the Western Appalachians. Mine drainage impacts were < 1% of the population in the Blue Ridge, Piedmont/Coastal Plain and Ridge & Valley ecoregions. Overall, using EMAP data in the mid-Atlantic study region, 17,000 km of streams were impacted by acid mine drainage (Table 3). Of this impacted length, 1480 km were acidic and would be toxic to most aquatic organisms. Similar (order of magnitude) estimates of regional condition have been made by other surveys (Table 3). Note, however, that there are large differences among the surveys in exact study area boundaries, sampling frames (maps used), rigor, and estimation/quantification methods. Thus, a direct comparison of the surveys, especially for temporal trends is not appropriate. However, taken together, these results do provide good bounds on the extent of the mine drainage problem. In addition, in the late 1970s, Dyer (1982a,b,c) conducted an extensive survey of mine drainage effects by sampling a mined and unmined small watershed (first order perennial stream) in every coal mining county in Appalachia. The data was used to illustrate the changes in streamwater chemistry and turbidity due to mining but no attempt was made to quantify the extent of the problem across the region. Dyer sampled 118 watersheds in West Virginia, 9 in Maryland, 31 in Virginia, and 86 in Pennsylvania.

As another example of regional vulnerability analysis, we took the EMAP data and developed another chemical classification for acidic deposition effects. We discarded all sites in the mine drainage impacted class and identified those sites with an acid neutralizing capacity (ANC) < 25 ueq/L. Sites with ANC < 0 are chronically acidic and sites with ANC between 0 and 25 ueq/L typically become acidic during storm episodes (Wigington et al., 1990). A regional vulnerability map showing the effects of acidic deposition was made using the same process as the mine drainage map. The ecoregions most impacted by acidic deposition were the Forested Mountains subecoregion in the Central Appalachians (31% of the length impacted by acidic deposition) and the North-Central Appalachians (27% impacted, Fig. 4).

The overall condition of stream benthos is illustrated in the map showing the ecoregion aggregation of SBII scores (Fig. 5). Most of the mid-Atlantic ecoregions had benthos impairment in 25-50% of their stream length. The highest degree of impairment was in the Piedmont/Coastal Plain where 78% of the stream length was impaired (SBII > 20). The ecoregion with the least amount of impairment was the Blue Ridge Mountains (22%, Fig. 5). Note that the benthos impairment will reflect all stressors on stream biota not just acid mine drainage (Fig. 3) and acidic deposition (Fig. 4). There are many other stressors in the region that will negatively impact the stream biota (e.g., agriculture, habitat alteration, point source pollution). The SBII score is an aggregation of all the stresses on the stream that will effect the stream benthos.

DISCUSSION

TABLE I. PROPOSED 10 METRICS FOR COMPOSITE POOL or Riffle SAMPLES AT EMAP AND MAHA STREAM SITES OF USEPA REGION III

Metric	Value				
	1	2	3	4	5
1. Number of Taxa	> 30	20 - 30	10 - 19	5 - 9	< 5
2. HBI	< 3.0	3.1 - 4.5	4.6 - 6.0	6.1 - 8.0	> 8.0
3. No. Individ./Taxon	< 4.0	4.0 - 6.9	7.0 - 10.0	10.1 - 20	> 20.0

4.	% Intolerant Taxa	> 40	26 - 40	10 - 25	1 - 10	0
5.	% Non-insects	< 20	20 - 39	40 - 69	70 - 90	> 90
6.	% Chironomids	> 50	36 - 50	26 - 35	20 - 25	< 20
7.	% Ind. Dom. Taxon	< 20	20 - 35	36 - 50	51 - 80	> 80
8.	% EPT Taxa	> 50	26 - 50	11 - 25	1 - 10	0
9.	EPT Index	> 25	11 - 25	5 - 10	1 - 4	0
10.	% Oligo. & Leeches	0	1 - 4	5 - 7	8 - 10	> 10

The total SBII score is used as follows to determine biological condition:

Excellent	Good	Fair	Poor	Very Poor
0 - 16	17 - 25	26 - 32	33 - 41	42 - 50

Nominal (0 - 25); Marginal (26 - 32); Subnominal (33 - 50)

Table II. Ecoregion Aggregations used in Mapping Regional Vulnerability from EMAP Data.

Aggregate Name	Omernik Level III/IV Ecoregion Name (Code) {Woods et al., 1996}
Western Appalachians	Western Allegheny Plateau (Level III #70)
Northern Appalachians	Northern Appalachian Plateau (Level III #60)
North-Central Appalachians	North-Central Appalachians (Level III #62)
Central Appalachians	
Greenbriar/Cumberland	Greebriar Karst (#69c) and Cumberland Mts. (#69d)
Mixed Land Use	Uplands & Valleys of Mixed Land Use (#69b)
Forested Mountains	Forested Hills and Mountains (#69a)
Ridge & Valley	Ridge and Valley (Level III #67)
Blue Ridge	Blue Ridge Mountains (Level III #66)
Coastal Plain/Piedmont	Northern Piedmont (#64), Southeastern Plains (#65), and Mid-Atlantic Coastal Plain (#63)

Table III. Regional Estimates of Mine Drainage Impact

	Mid-Atlantic Region	
Survey (Year)	Acidic Mine Drainage Length (km)	Total Mine Drainage Length (km)
Probability Surveys		
EMAP/MAHA (1993-1995)	1,480	17,000
NSS (1986)	3,470	6,817
Data Compilations		
Appalachian Regional Comm. (1965-1969)[a]	8,990	15,800
U.S. Fish & Wildlife Service (1963)*	9,280	not made
	Severe Fish Loss	Severe & Some Fish Loss
Region 3 Biologists (1993)	3,640	7,260

[a]Appalachian Regional Commission estimates were made for all of Appalachia in the late 1960s by consulting with state and local agencies, reviewing reports, and field reconnaissance (Appalachian Regional Commission, 1969; Federal Water Pollution Control Admin., 1969). U.S. Fish & Wildlife Service estimates were made in 1963 by summarizing reports from each State's Fish and Game Department (Kinney, 1964).

FIGURE LEGENDS

Fig. 1. Sample site location for the National Stream Survey (triangles) and EMAP (dots) in the mid-Atlantic.

Fig. 2. Data from EMAP, NSS and the Region 3 fish biologist survey are shown together as a dot and line map. The stream traces on the map are data from the fish biologist survey; red stream lines are in the severe fish loss class, blue stream lines in the some fish loss class. The EMAP (dots) and NSS (triangles) sites with mine drainage impact are also shown. Acidic, mine drainage impacted sites are shown in red, non-acidic mine drainage impacted sites are shown in blue.

Fig. 3. Map showing the percent of mine drainage impacted stream length in each aggregate ecoregion. The aggregate ecoregions are summarized in Table 2. Estimates of regional condition were made using the EMAP probability sample data and site population expansion factors.

Fig. 4. Map showing the percent of acidic deposition impacted stream length in each aggregate ecoregion. Acidic deposition impacted streams are defined as those with acid neutralizing capacity < 25 ueq/L and no mine drainage influence (observed streamwater sulfate concentrations dominated by deposition levels of sulfate). The aggregate ecoregions are summarized in Table 2. Estimates of regional condition were made using the EMAP probability sample data and site population expansion factors.

Fig. 5. Map showing the percent of stream length with stream benthos impairment in each aggregate ecoregion. Impairment was defined as having an SBII score > 20. The aggregate ecoregions are summarized in Table 2. Estimates of regional condition were made using the EMAP probability sample data and site population expansion factors.

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